First Order Memory Dump on the E766/E690/E910/E895/E907 Threshold Cerenkov Counter

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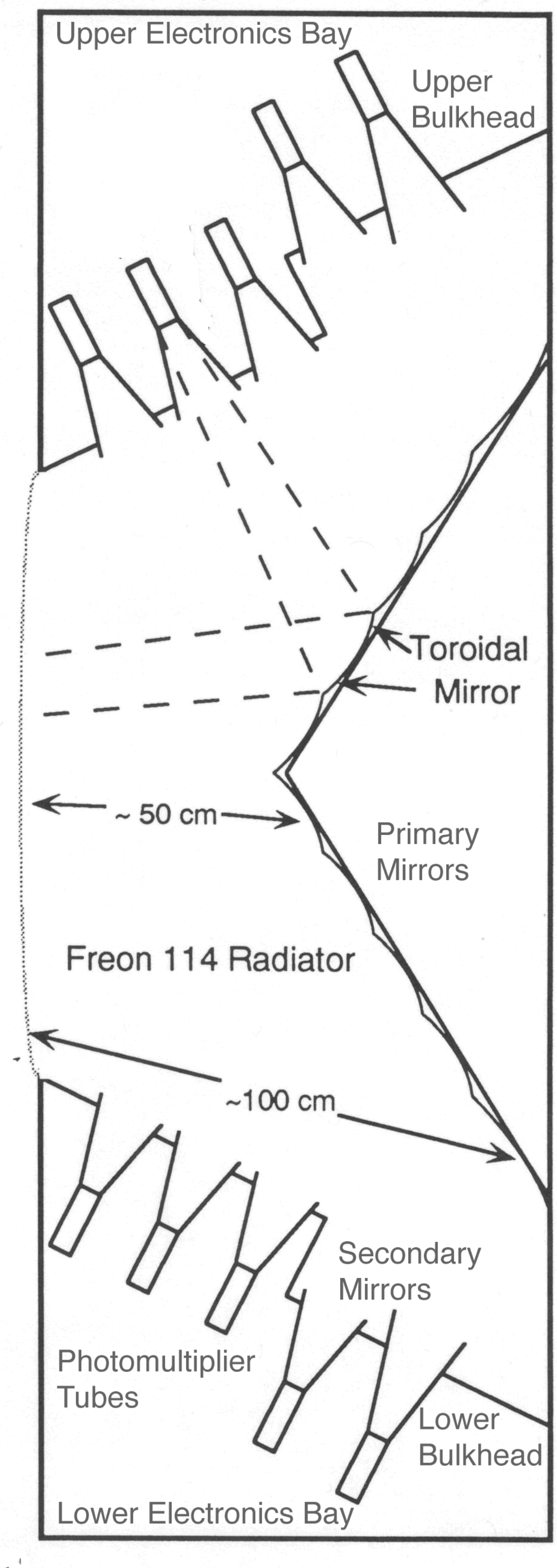
Introduction

This documents describes much of what I know or can recall about the threshold Cerenkov counter that we intend to use for Fermilab E907. I assume familiarity with the literature posted on the E907 web page: http://ppd.fnal.gov/experiments/e907/Cerenkov/Cerenkov.html and people and documents referred to therein. The purpose of this document is to provide as much information as possible for people working with this detector system.

The Box

The Cerenkov counter box includes essentially all of the Cerenkov counter components. The box provides the mechanical platform for the optics; it provides a light-tight, gas-tight volume viewed by the photomultiplier tubes. It is designed to minimize the amount of material along particle trajectories. In order to assemble components and align the optics, it generally rides on an undercarriage capable of rolling in and out of position. In the case of E907, this will be lateral motion with respect to the beam line.
The box dimensions are 9’3”x10’11”x3’9” (2.8194m x 3.3274m x 1.143m).
The front and back of the box have openings that are closed by thin windows. Two primary mirror planes are mounted on a 3-point support that is used to orient the planes to optimize the focus. The secondary mirrors and photomultiplier mounts are located on the upper and lower gas volume bulkheads. The photomultiplier tube bases are located in electronics bays outside of the radiating gas volumes above and below the upper and lower bulkheads. Figure 1 shows a side view of the Cerenkov detector with the box nomenclature.

The front window consists of a Kevlar, Tyvek, and Aluminum composite fabric bonded to an aluminum frame. This provides a strong, gas-tight and light-tight window of very low mass. The window is shown in Figure 2. The back window was redesigned for BNL E895. This new window consists of an aluminum frame, which attaches to the box and makes the gas seal and a composite laminate which offers structural strength and the necessary gas and light tightness. The window is shown in Figures 3 and 4.



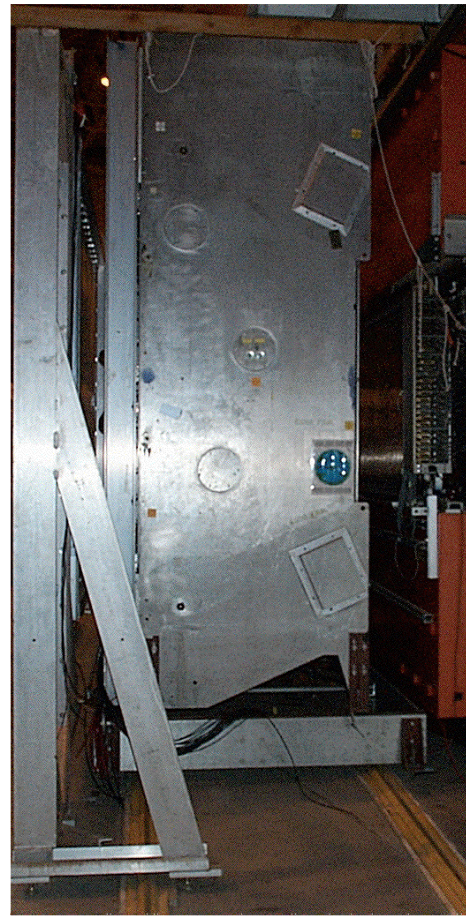


Figure 1. A schematic view of the cerenkov counter is shown on the left with the major components labeled. A picture of the cerenkov counter as it appeared in BNL E910 is shown above. In the picture, the beam enters from the right. The cerenkov box is sitting on the undercarriage, which is sitting on the yellow rails. This allowed the box to be moved out of the beam to beam left. The three circular ports are the mirror adjust access ports. The two square boxes are for photomultiplier tube clearance.

Figure 2. Front of cerenkov counter that is pushed out of the beam to the left on the rails. The golden colored fabric is the front window.

Figure 3. Back of cerenkov counter. Golden material is the Kevlar backing of the laminated composite window.

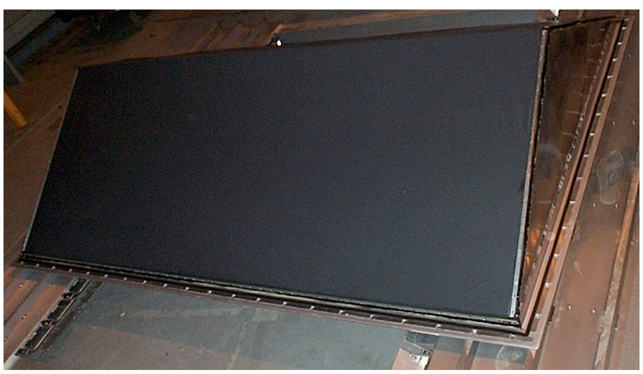


Figure 4. The back window removed from the counter. The inner surface is shown here.

Once the front and back windows are removed the primary mirror planes, and the secondary mirrors are visible. The upper and lower primary mirror planes have 48 mirrors (each) which are glued to a composite board. The board can be oriented to provide optical alignment of the system. The mirrors are made from 1mm thick glass. The replacement mirrors no longer exist; so great care must be given to handling the primary mirrors. Currently, these mirrors are stored in wooden boxes in the ME beam line at the Fermilab Meson Lab. The mirror planes are shown in Figures 5, 6, 7 and 8.

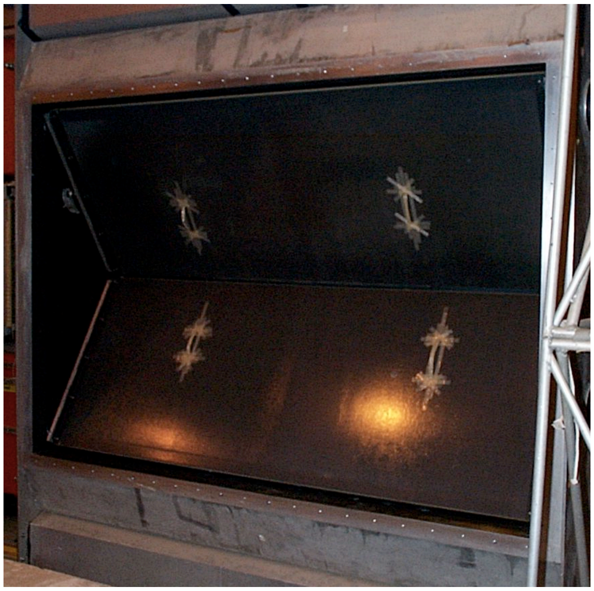


Figure 5. View of back of cerenkov counter with rear window removed. The primary mirror planes' carbon fiber skinned composite boards are visible. The strapping tape forms a simple handle system to extract the planes. The planes are captured on the sides; the aluminum angle can be seen on the left boarder of the mirror planes.

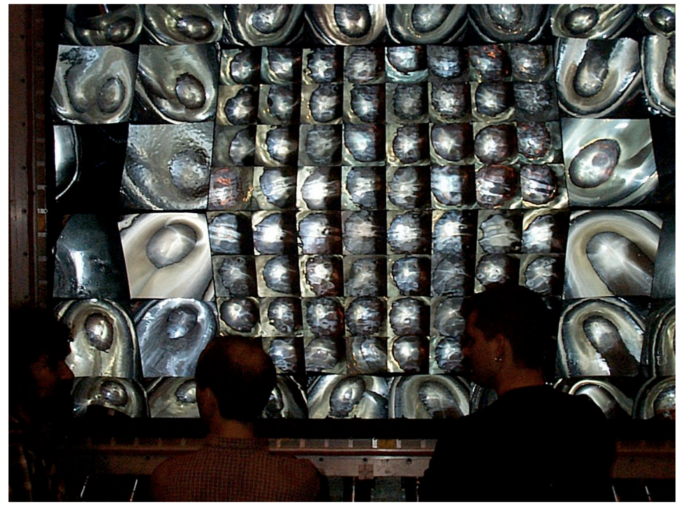


Figure 6. View of front of cerenkov counter with front window removed. The primary mirrors are reflecting the image of the secondary mirror/photomultiplier tube associated with each optical element. The three mirror sizes are evident in this picture.

Figure 7. The secondary mirrors are visible with the lower primary mirror plane removed from the box.

Figure 8. The lower primary mirror plane placed in its shipping crate.

The mirror support fixtures are removed from the box once the primary mirror planes are removed. These support fixtures are stored in David Christian's office at Fermilab (on the 10th floor of Wilson Hall). Figures 9 and 10 show the box empty of the primary mirror planes.

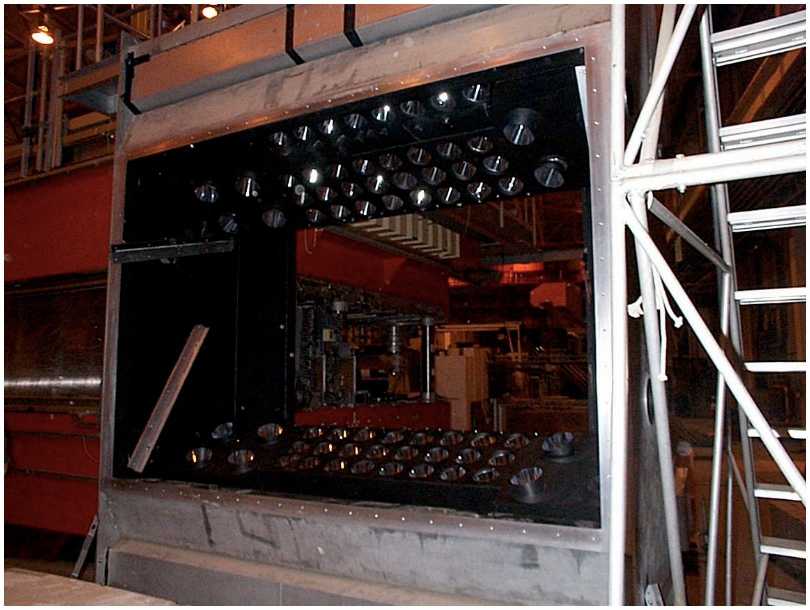


Figure 9. Rear view of box with no primary mirror planes. The primary mirror plane fixtures are seen on the left side of the box.

Figure 10. Details of the primary mirror plane support fixtures.

Once the photomultiplier tubes, bases and magnet shielding, the windows were put onto the box, a protective plywood window was placed over the windows. The box was then removed from the undercarriage and shipped to Fermilab. The box is currently stored at Fermilab's Proton lab PC4 enclosure.

A schematic of the Cerenkov, with those items that are taken out of the box, is shown in Figure 11.

Details of the optics design and fabrication can be found in David Chrisitan's note on the Cerenkov counter.

The Photomultiplier Tubes, et cetera

The photomultiplier tubes (pmt's) are Thorne EMI 9954B that are selected on the bases of tube diameter (to ensure a good seal). The pmt's are further modified with a coating of wave-shifter on the photocathode window surface to increase the detection efficiency by shifting the blue Cerenkov light in to the green.

The pmt's are run with low gain using 7 of the 12 available multiplication stages. This was done to reduce gain variations due to environmental conditions (e.g. temperature variations) and to eliminate the need for individual high voltage

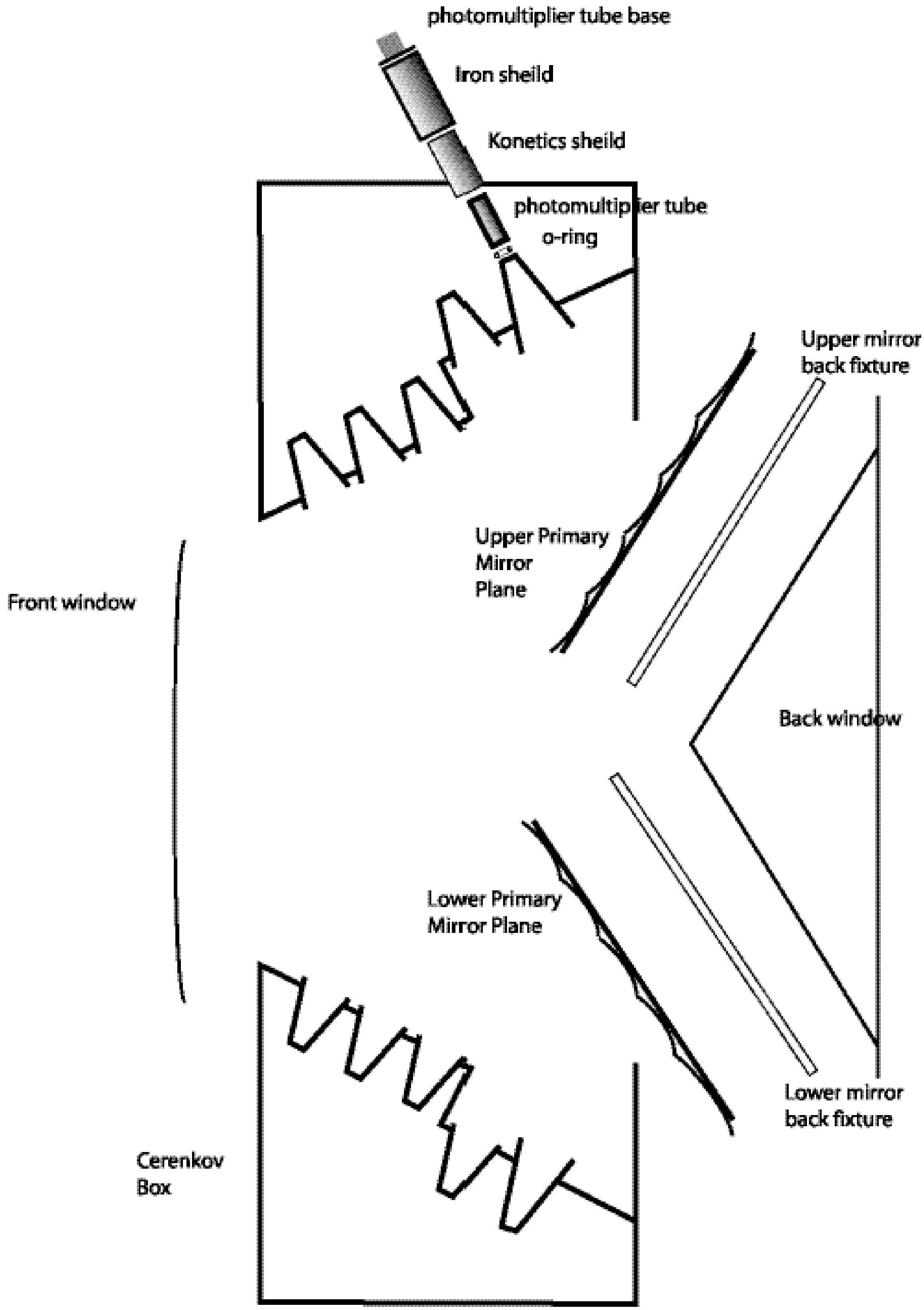


Figure 11. A view of the Cerenkov counter that identifies the various pieces that are removed from the box.

settings for each tube. The pmt base is shown in Figure 12.

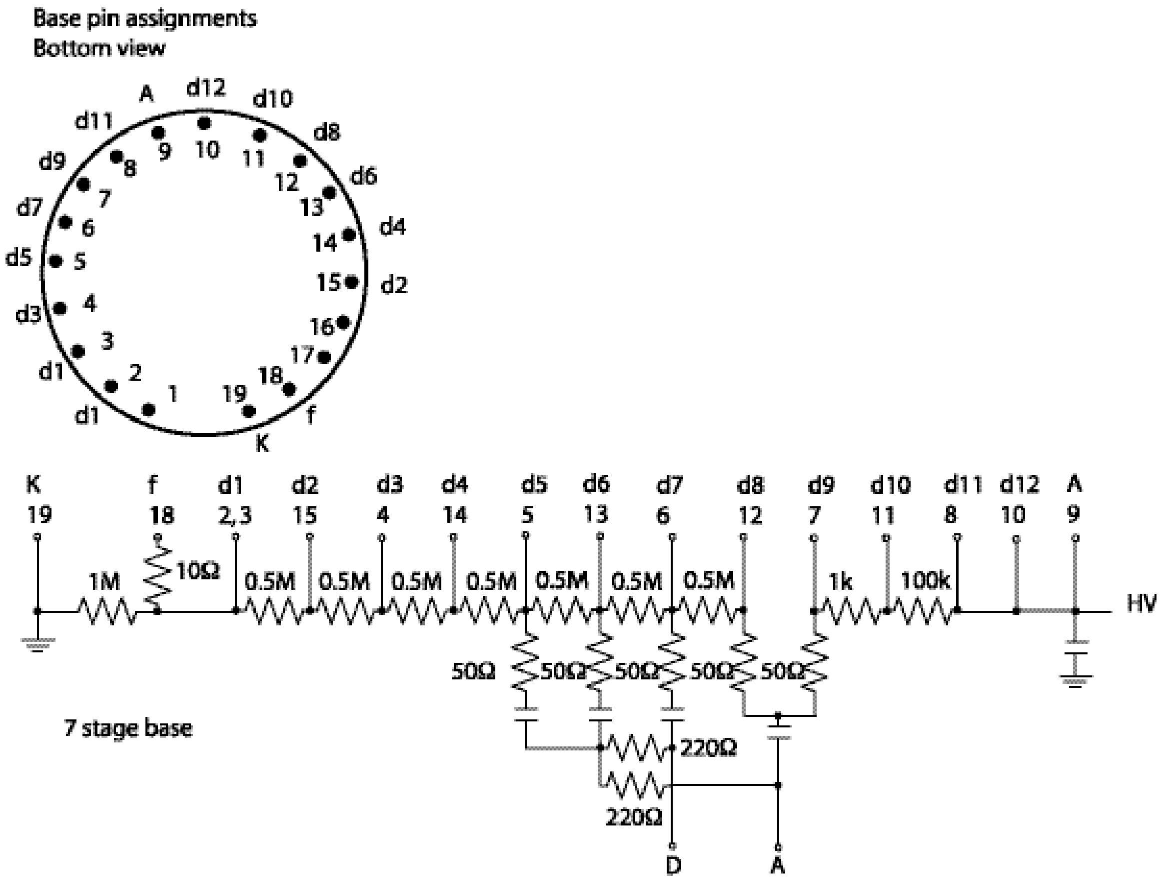


Figure 12. The base pin-out and schematic diagram of the photomultiplier tube voltage divider and signal output “D” and “A” to amplifier.

A differential amplifier is provided in each base to increase the signal to a 1 V. maximum level. This amplifier utilizes an ECL line driver in multiple stages. Sensing the voltage difference between the final dynode stages (the 7th dynode), and the anode stage (the 8th through 12th stages and the anode), the ECL 10H116 line receiver produces a differential output that is further amplified for analog and digital outputs. The digital output is generated if the input signal exceeds an externally set threshold. A schematic of the pmt amplifier is shown in Figure 13.

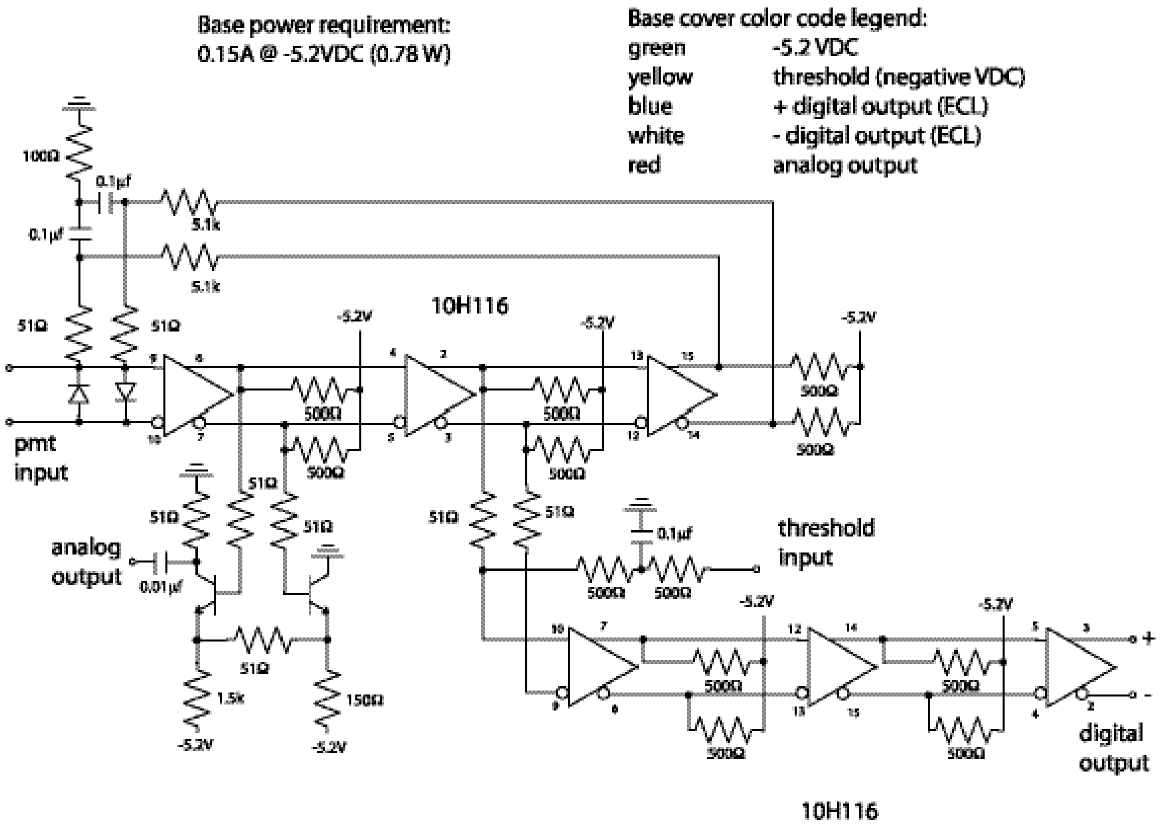


Figure 13. Schematic diagram of pmt base amplifier/discriminator. Refer to Nevis DWG. 4143-2 2/28/83.

The base is shown in Figures 14a-f. The location of the HV, signal, amplifier power and threshold are seen in Fig. 14a. The pmt socket can be seen in Fig. 14b. The angle tabs on either side of the base provide the means of connecting the base to the iron shield. The connection is made by trapping a spring between the tab and a washer (captured by the screw head). The force of the compressed spring seats the photocathode against an o-ring, setting the position of the pmt, and sealing the gas volume.

Figures 15a-e show the base being disassembled. The steps are to remove the detent-captured part of the Aluminum box, unscrew the socket (Figs. 15a-b), unscrew the subminex connector bolts releasing the amplifier (Figs. 15c-e). The amplifier board can be further removed by unsoldering the signal wire connections to the “Dynode” and “Anode” points (denoted by D and A in Figure 12). The pmt socket can then be removed by unsoldering the HV lead.

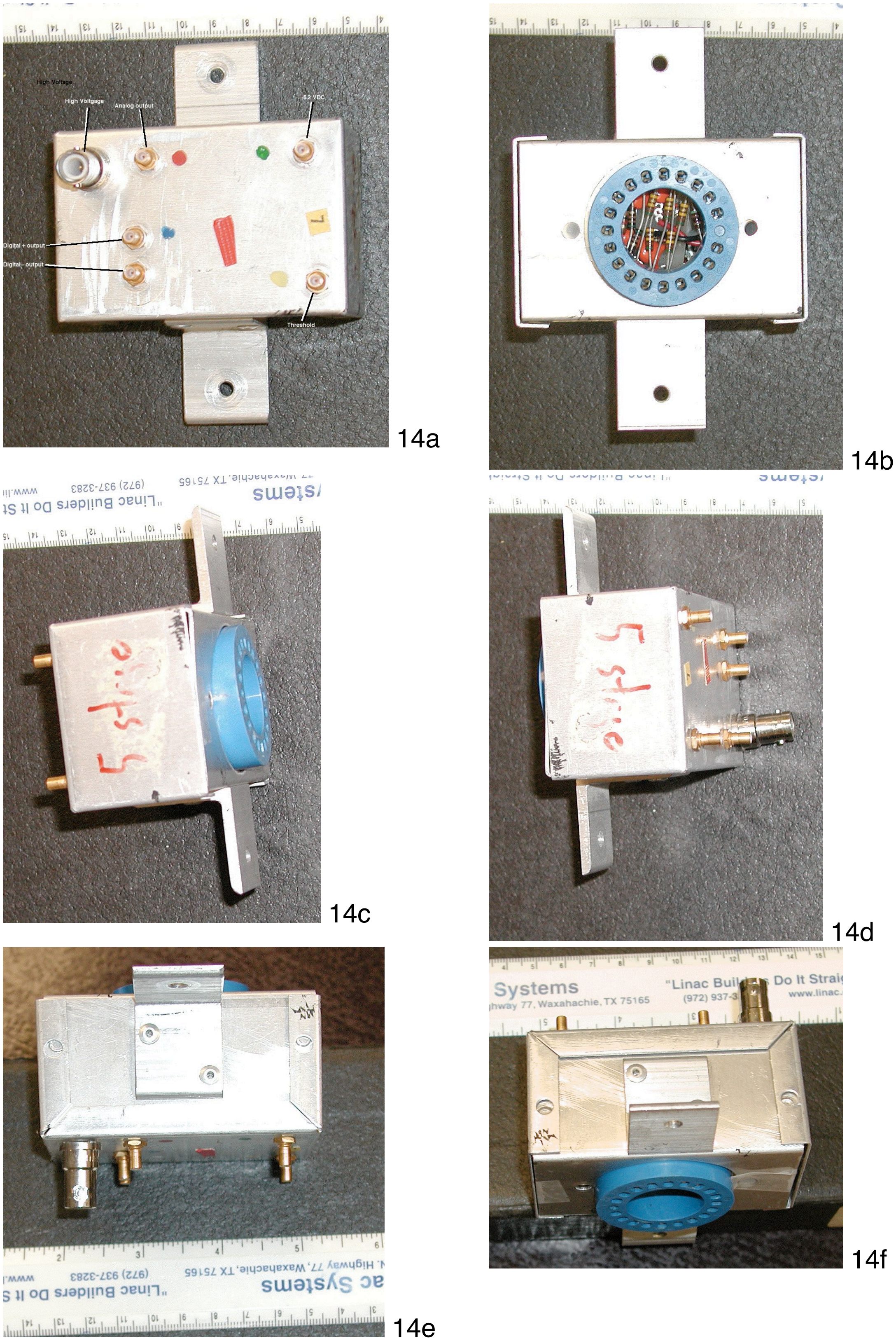
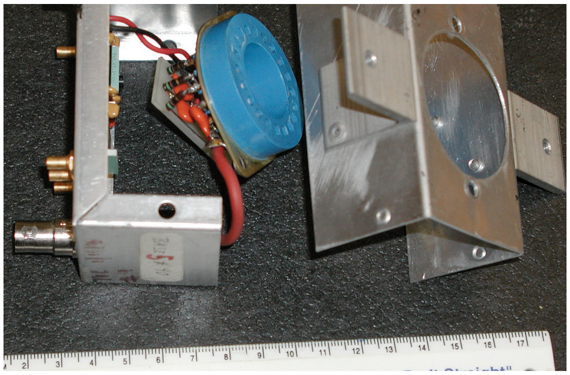
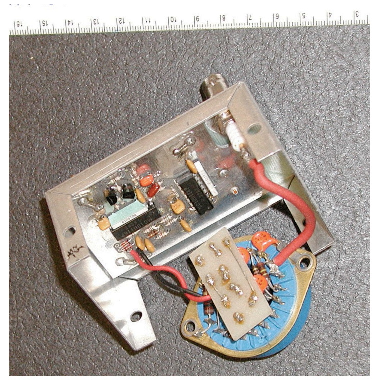


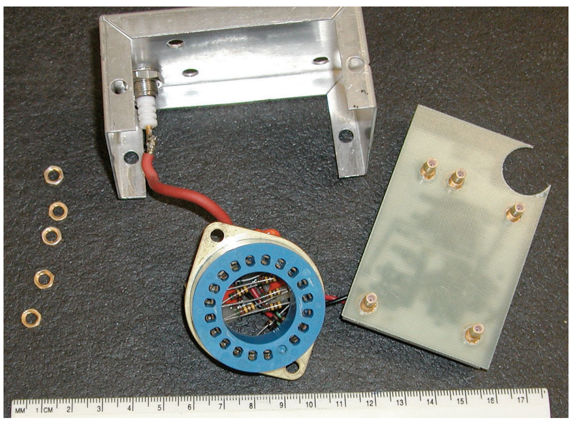
Figure 14a-f. External views of the Cerenkov pmt base assembly.



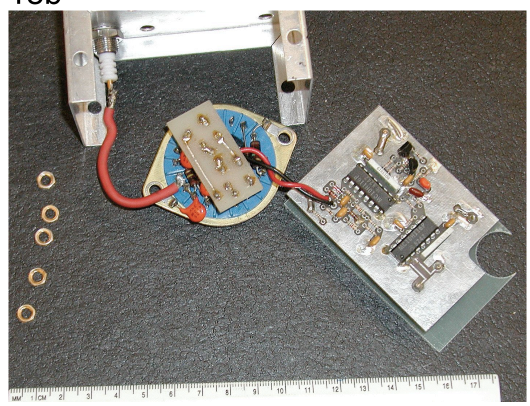
15a



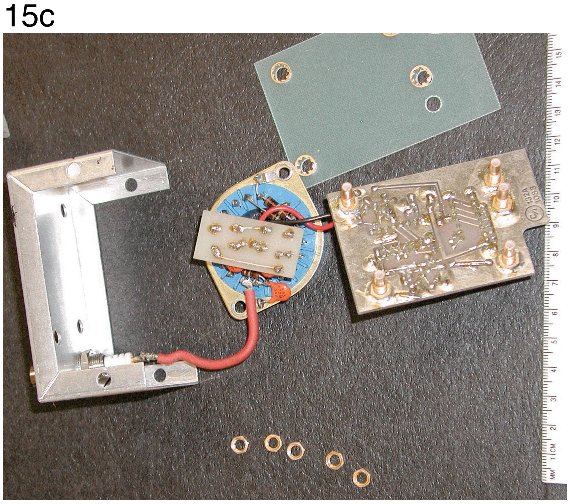
15b



15c



15d



15e

Figures 15a-e. a-b) front box cover removed with socket unscrewed from box; c-d) shows the amplifier card released from back box cover by unscrewing retaining nuts; e) shows the insulating FR-4 sheet removed from the amplifier card. Most frequent failures are the front-end diodes, and the first 3 amplifiers of the input 10H116 line receiver.

A generic test setup is shown in Figure 16. A photomultiplier is plugged into a test base (one of which is selected from the set). The base inputs and outputs are attached to the appropriate devices. The high voltage can be as high as 2200 VDC. (Note that as of the writing of this memo, the HV connectors may not have been reviewed by Fermilab safety committee). The threshold should be setup to a low current voltage supply capable of supplying –0.8 V to –1.8 V (the ECL voltage swings). The “digital +” output goes to an ECL-to-NIM converter and the output of the conversion to channel 2 of the scope. The "analog" output goes to channel 1 of the scope. The signal, power and threshold cables must have the "subminex" style cable ends, generally on a RG-174 50ohm cable, standard LEMO connectors on the other side. These cables will have to be found, scrounged or made. The high voltage cable is "standard".

The photomultiplier tube, base, scintillator and radiation source are placed in a dark box with the cables accessible in a light area. As the photomultiplier tube is brought up to voltage, the analog signal should show up on the oscilloscope screen (assuming the threshold is set correctly; -340 mV is typical maximum pulse height, widths can be as small as 4ns). If the signal is above threshold, the digital output should also be giving signals. It is possible that the tubes undergo periodic, high rate pulsing (bursts), or spark (very large signals). Tubes or bases may have low gain, etc. Connectors to cables can be bad, tube-to-base connection may be bad, etc. (A set of 72 tubes which we may be able to sort through to find replacements can be found in Lab G attached to the old E690 rear scintillator hodoscope. These existed at least up to summer 2001. They should be recovered as soon as possible for possible use in E907).

A useful study would be to plot the threshold voltage setting versus the signal minimum signal pulse height. This can be done by triggering the scope on the digital output signal and measuring the minimum analog signal pulse height for a given setting of the threshold voltage. The total integrated charge for a given pulse height and duration can be estimated by $\Delta Q/\Delta t = I = V/R$, which can be solved for the charge: $\Delta Q = \Delta t \times V/R$. This estimate is done on page 57 of the "E910 Cerenkov Logbook #1". For $R = 50\Omega$, $V = 95$ mV, and $\Delta t = 38.9$ ns, the total charge (assuming a square waveform) is $\Delta Q = 74$ pC. E895 reported that the 17 mV threshold corresponded to a 2 photoelectrons. This has to be checked (measuring the pulse height spectrum from the base). Assuming this statement would imply the single photoelectron integrated charge to be less then 12 pC. One photoelectron sensitivity is a goal for E907 operation.

Properties of the Thorn/EMI 9954B can be found in the catalog obtained from the spin-off company: electron tubes (http://www.electrontubes.com). The tube has a maximum diameter of 51.5 mm and a length of 133 ± 3mm. The photocathode active area has a 46 mm diameter. The tubes have the "hard base" configuration in which the pins exit directly through the glass at the bottom of the tube. The tube window is standard borosilicate. This window passes radiation above 300 nm wavelength. The transmission is 90% at 375 nm, 50% at 300 nm and 10% at 275 nm. Borosilicate glass has radioactive elements at the limits: <60000 ppm K, <1000 ppb Th and <1000 ppb U. The number of decays per minute is < 400 /min. The tube has 12 dynodes with Be-Cu coating in a linear focused configuration. This configuration has typical rise times of 1.8 – 2.7 ns, a transit time jitter of 0.5 – 1.2 ns with a single electron jitter of 2.2 ns. With the base design shown in Figure 12, the $V_{d\text{-}d}$ is 244 V, which would deliver a peak anode current of 122 mA in a 12 dynode base configuration. The bialkali (K-Cs-Sb) photocathode has a peak quantum efficiency of 28% at 400 nm. The dark current emission is typically 7.5 nA/cm^2 corresponding to roughly 300 dark counts/s. In a 7 stage base configuration with gains ranging from 2×10^4 to 2×10^5 the output currents range from 1 to 10 A/lm, respectively, with the higher of these being the recommended maximum limit.

Currently, electron-tubes can supply the 9954B at roughly $588 per tube in 3 to 4 weeks [according to Mike Avery, Electron Tubes West Coast Office (760) 471 1053, GBMICK@aol.com].

The tubes used in the Cerenkov counter are coated with a wave shifter to increase their sensitivity to the blue Cerenkov light, by shifting the light towards the green. The coating can be performed at existing facilities at Fermilab, which must be scheduled. This involves dipping the photocathode into the appropriate wave shifter solution and allowing the solution to dry onto the photocathode window. Details can be obtained from David Christian.

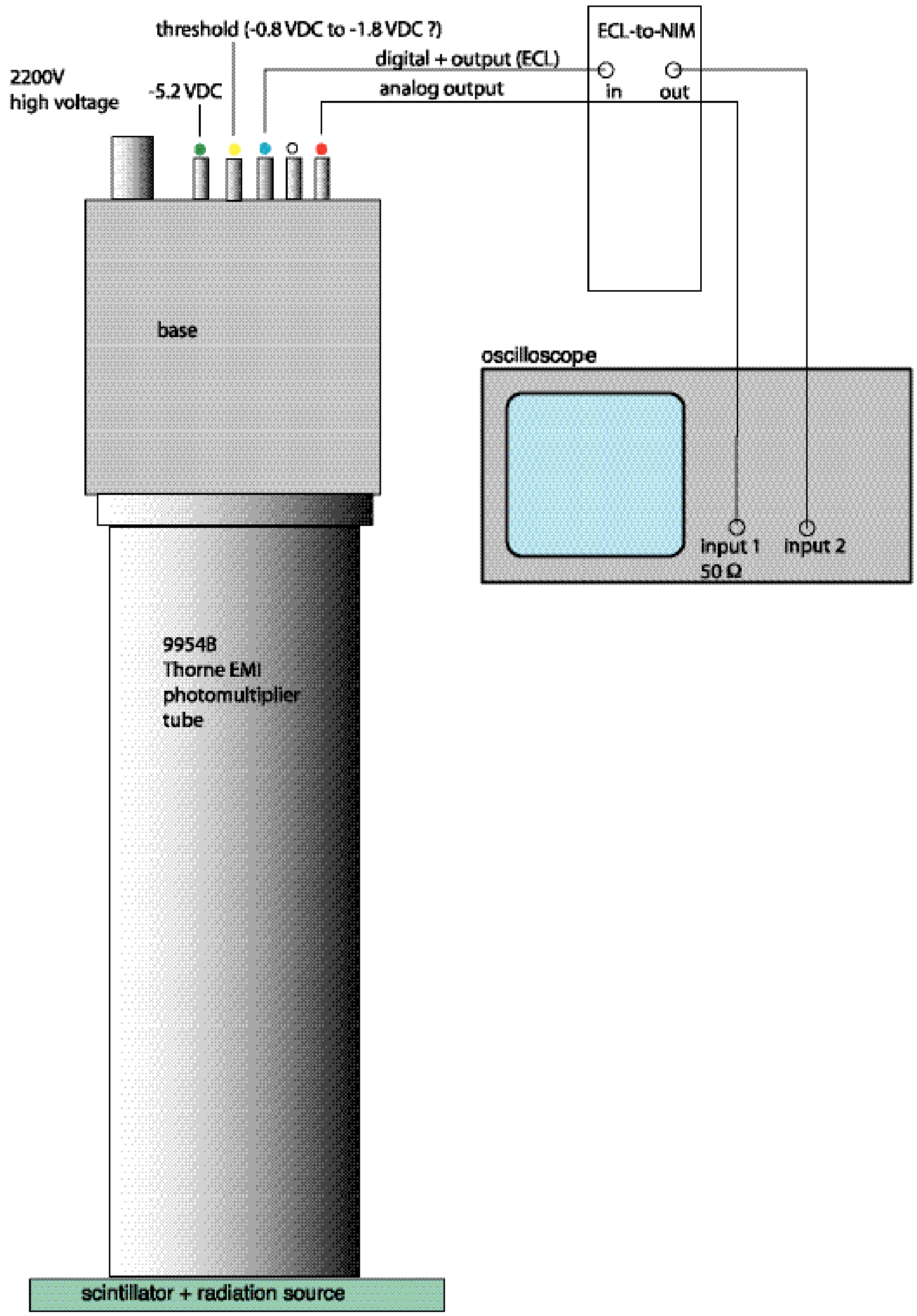


Figure 16. A generic test arrangement for the photomultiplier tubes and bases. Note that phototube/base/scintillator assembly should be located within a “dark box” for these tests.

Gas system

The gas system for the Cerenkov counter is rudimentary. The counter system is filled from the bottom of the volume, where the Freon 114 slowly displaces the air. Once this vessel is full, the system is switched to “top off” the vessel. In E895, a large bladder volume provided most of the top off reservoir, allowing the Cerenkov to “breath” as a function of atmospheric pressure. The pressure changes are conveyed to the gas volume through the front window, causing the gas level to rise and fall.

Figure 17 shows the original E690 gas system.

The possibility of recovering the Freon from the counter should be investigated, as single fills for the duration of the experimental run are likely to be the operating mode for E907. In the event that a pmt must be changed during a fill, some additional Freon will be required to refill the counter. Procedures for reducing the amount of leakage during a pmt change should be reviewed or developed for E907. The total volume of the gas volume is of order 120 cu. ft.

Figure 17. The E690 gas system (composite picture). The Freon pressure at the top and bottom of the vessel are measured by the two helix pressure gauges noted on either side of the stainless steel tubing. The original E766 plumbing system was made of white PVC tubing, which was found to be translucent (causing greatly increased noise rates in pmt's near the gas inlets). The Freon is supplied via the small black tube at the bottom of the counter. A bubbler/barometer allows the gas level to be detected within the vessel providing a check on the fill progress, and the level of the gas when full (but leaking). The two valves seen at the bottom of the counter allow the fill to occur either at the bottom of the vessel, as is the case on the original fill, or at the top of the counter, which is the "top off" mode. E895 added a large bladder at the top of the counter, which was partially filled and allowed the atmospheric pressure to change without emptying and filling the counter. The new back window and the addition of the bladder should make one fill possible, with no additional Freon required for the run.

Mirror Alignment

The mirror alignment is accomplished by observing the photocathode images in the mirror mosaics for the upper and lower mirror planes. Viewed from the position of the target, the photocathode images should be centered in each mirror. The designed distance from target to the mirror plane apex is 109.25”. The only motion allowed is the positioning of the upper and lower planes (each are independent). There are two degrees of freedom for two of three support points.